New Bedford Harbor: Confined Aquatic Disposal Cells

Introduction

This document summarizes key components of the use of Confined Aquatic Disposal (CAD) cells for the Boston Harbor Navigation Improvement and the Providence River and Harbor Maintenance Dredging Projects. This information is compiled to support the US Environmental Protection Agency (EPA) in determining if this technology is applicable for the future disposal of material dredged from the New Bedford Harbor Superfund site which has been deemed unsuitable for open-water disposal.

New Bedford Harbor in Massachusetts is located on the north shore of Buzzards Bay and is the estuary of the Acushnet River. Past industrial development in the surrounding area has resulted in the contamination of harbor sediments with polychlorinated biphenyls (PCBs) in excess of 100,000 ppm.[1] In 1983, the harbor and portions of the surrounding bay were placed on the EPA's National Priority List as a Superfund site. The initial Record of Decision (ROD) was signed in 1990 and included dredging of the most contaminated sediments and pumping them through a floating pipeline to an interim shoreline confined disposal facility (CDF) near the Harbor as the remedial alternative. A subsequent ROD determined that the sediments would be processed through a dewatering facility and shipped via rail and truck to approved landfills. As of Fall 2007, approximately 84,000 cy of contaminated sediment have been dredged and processed.[2] The total dredged sediment for the project is estimated at almost 900,000 cy and a budget in excess of $340 million, consequently, CAD cells are being considered as an alternative remedy that is both environmentally and economically practical.

Confined Aquatic Disposal cells reduce the risk from contaminated sediments by storing them in a depression in the bottom of an aquatic system and then covering, or 'capping' them with a layer of clean sediment. The top of the CAD cell capping material is at, or below, the bottom of the ocean or river channel. The three types of CAD cells include: naturally occurring depressions in the sea floor, sites left from previous mining activities such as beach nourishment borrow sites, and newly dredged sites created specifically for holding contaminated sediments.[3] Since its launch in 1977, the capping of contaminated sediment has been utilized and extensively studied under a formal US Army Corps of Engineers program entitled Disposal Area Monitoring System (DAMOS).[4] The results of these studies have led to stringent testing protocols and improved management practices to ensure that no significant adverse environmental impacts result from disposal operations. The New England District Corps of Engineers (the Corps) has successfully utilized disposal into CAD cells as remediation option for the Boston and Providence Harbor maintenance projects. These projects provided specific lessons learned for CAD cell deployment and will serve as the basis of comparison for planning the remedial effort at the New Bedford Harbor.

Boston and Providence Projects

Boston Harbor Navigation Improvement Project (BHNIP) was the first large scale use of CAD cells in the United States.[5] The cells were excavated beneath the shipping channel into the parent sediment layer of Boston Blue Clay, a homogeneous, high-strength clay with low water content and low permeability. Approximately 1 million cubic yards (cy) of sediment containing elevated concentrations of metals and organic compounds (primarily PCBs and naphthalene) were released into the cells and then capped with clean, sandy sediment from the Cape Cod Canal.[6]

The Providence River and Harbor Maintenance Dredging Project (PRHMDP) also utilized CAD cells that were placed directly in the navigation channel at the head of Providence Harbor. The cells were dug into parent material of glacial till (mixture of gravel, sand, and clay) and subsequently filled with approximately 1.2 million cy of sediment contaminated primarily with heavy metals.[7] To date, these cells remain uncapped and continue to provide a disposal option for other material deemed unsuitable for unconfined open water disposal.

CAD Cell Construction

The dimensions of each CAD cell are a function of the required storage volume, subsurface geological conditions, thickness of the disposal material, side slopes for wall stability, and the aspect ratio (length divided by width). When placing cells in navigation channels, additional considerations must be given to any future plans to deepen the channel, the degree of heavy propeller wash during ship maneuvering over the cells, the structural integrity of nearby piers and seawalls, submarine utility lines, and the proximity to open ocean outlets.[8]

CAD Cell Containment Design

Areas being considered for submarine disposal must meet geotechnical and engineering design criteria for construction of CAD cell walls. Unlike near-shore confined disposal facilities (CDFs), which can be supported by berms or sheet pile walls, CAD cells are solely dependent on the engineering properties of the surrounding sediment for the stability of their side slopes and overall size. Configuration and planning must take into consideration the initial depth-to-bedrock, depth to mudline, depth of sediment from mudline to bedrock, and the geologic stratigraphy from the mudline down. The presence of anything that might restrict CAD cell excavation must also be considered, such as bedrock precipices or sunken debris.

Sediment characteristics can also affect the transport of contaminants across the boundary between maintenance material and native sediment. The potential for groundwater flow to affect aquifers or to transport contaminants out of CAD cells is not likely, but should be considered.[9] Usually, the maintenance material will be fine grained with low permeability so that any groundwater flow is more likely to be diverted around the cell than through it. Conversely, CAD cells constructed in finer sediments, such as the packed clay in Boston Harbor, are less likely to allow the release of dissolved contaminants into the surrounding sediments.

CAD Cell Excavation

During removal of contaminated surficial sediments (also called maintenance material) from both Providence and Boston Harbor CAD cell footprints, the project water quality certificates (WQC) required the use of closed environmental clamshell buckets that met specified performance standards for turbidity and total suspended solids (TSS). The smaller buckets, with capacities between 7 and 32 cy, also allowed for more accurate segregation of clean parent material, suitable for offshore disposal, from maintenance material that would eventually be placed back into the completed cells. As the cells were deepened, Boston Harbor continued to use closed buckets to minimize resuspension of the silty Boston blue clay. PRHMD also used 7-32 cy capacity closed buckets for removal of maintenance material, but the more compacted and coarser grained sediments of the subsurface glacial till in Providence Harbor allowed for the use of open buckets in order to expedite removal of parent material.

CAD Cell Construction Sequence

On both projects, a series of cells was constructed with smaller cells being dug first because maintenance material from the first cell must be stored until there is a place for disposal. Each subsequent cell is built larger than the previous one. The BHNIP was initially scheduled to have 52 individual CAD cells. During construction, the contractor proposed larger cells in order to reduce the area lost to separator walls between smaller cells. A total of 9 cells were finally constructed between Phase 1 and 2. The number of cells for Providence Harbor was also reduced, from 8 to 6, because the quantity of maintenance material was less than expected and because two smaller cells were combined after the separation wall between them was deemed unstable.

Several benefits to larger CAD cells have been noted. Larger cells help to reduce the amount of near-bottom surge which occurs when disposed material reaches the bottom with enough force to travel up the sides and settle around the apron of the cell.[10] The BHNIP notes several other benefits to larger and deeper cells including:[11]

- Greater degree of sequestration.
- Reduced potential for loss of material from CAD cells before capping because cells are further below the surrounding harbor bottom and less influenced by current and vessel passage.
- Preservation of potential harbor space for future projects.
- More efficient long term monitoring due to reduced number of cells.

From a logistical perspective, CAD cells reduce the transport distance from the dredge site to the disposal site. Upland disposal increases human health risks through dermal contact, volatile emission, groundwater pathways, and rail or truck accidents.[12]

Boston Harbor

Water quality control standards for CAD cell excavation in Boston Harbor were set separately for dredging of surface silts and for dredging of parent material. During BHNIP Phase I, samples were collected and tested at two locations: 500 ft. down current from the dredging and at a reference station 1,000 ft. up-current of the dredging. According to the WQC, the mixing zone was defined as 300 feet down current from the dredging activity. At this location, as well as within the mixing zone, the acute standards, defined as the one hour average concentration, were to be met at all times. The chronic standards, defined as the 4 day average concentration (for PCBs = 24 hour limit of exposure), were to be met at the edge of the mixing zone and beyond.[13]

The WQC set a performance standard for **TSS** concentration of 200 mg per liter at 500 feet down current of the operating dredge. In situ turbidity measurements ranged from 3 to 5 NTU at the reference station and were only slightly elevated, 5 to 9 NTU, at 500 feet down current of the dredge. TSS ranged from 4-5 mg per liter at the reference location, and 5 mg per liter at slack tidal conditions to 9 mg per liter at maximum flood at the down current station. A small plume was localized near the dredge bucket, which dissipated rapidly. Turbidity levels showed a maximum of 40 NTU twenty-five feet from the bucket which indicated that the TSS was still far below the performance standard.[14]

The Water Quality Certificate required sample collection at two locations during dredging of parent material: 300 feet down current from the dredging and at the reference site 1,000 feet up-current. Samples were collected at mid-water column depth and from within three feet of the bottom. Prior to the collection of samples, at 300 feet down current, a turbidity probe was deployed. After tracking the turbidity levels across the 300-foot boundary, samples were collected within any discernible plume. These samples were analyzed for **TSS**, arsenic, copper, and dissolved oxygen. In comparison to the dredging of the surface silts, a discernible plume was visible for a greater distance around the operating dredge. In situ measurements of turbidity at the reference site ranged from 3 to 7 NTU; 300 feet down current turbidity measurements ranged from 8 to 56 NTU. **TSS** values ranged from 8 to 60 mg per liter at the reference site and ranged from 19 to 48 mg per liter 300 feet down current, which was still far below the performance goal set by the WQC.[15]

Providence Harbor

During CAD cell construction activities for the Providence Harbor project, sediment plumes were monitored for spatial dimensions, turbidity and total suspended solids (**TSS**), and temporal dynamics at flood and ebb tides. (See PRHMDP Synthesis Report, Sec. 4.3 for Methods used) Near-field monitoring stations were located 230 to 260 ft. from the dredge and far-field stations were located 380 to 460 ft. away at depths of 5.9, 19, and 33 ft. At the near-field stations, mean turbidity was 8.9 to 13.4 NTU compared to average ambient levels of 1.5 to 4.0 NTU for the two monitoring days. Turbidity increased with depth at the far-field stations with average readings of 9.2 and 13.9 NTU and the frequency and duration of the turbidity pulses, caused by the dredge bucket cycle, were significantly diminished.[16]

Ambient **TSS** concentrations ranged from 8.5 to 22.5 mg per liter. As would be expected, highest concentrations of **TSS** (200-300 mg per liter) were found at water depths >39 ft. at the center of the plume where the dredge was working and extending outward across the width of the CAD cell. Vertical profiles of the flood tide survey indicated a rapid settling of suspended sediments within a relatively short distance from the source. By the time the plume had crossed the length of the CAD cell, **TSS** readings were higher than ambient readings by 25 mg per liter. At 750 ft down current from the dredging, some suspended sediments were dispersed along the channel bottom, but highest concentrations remained confined within the CAD cell. By 1,100 ft. down current and outside the CAD cell, the plume was approximately 330 ft. wide and generally confined to the bottom 7 ft. of the water column. By 1,700 ft. from the dredging operations, plume signatures could not be detected above background conditions.[17]

Recordings of **TSS** within the CAD cell during ebb tide were somewhat lower than those observed during the flood tide survey. However, maximum concentrations outside the CAD cell were slightly higher at 50 mg per liter above ambient readings due to the positioning of the barge closer to the edge of the cell. Distinct plume signatures were not detectable above background at 1,800 ft. down current.[18]

Water Quality during Disposals into CAD Cells

Boston Harbor

Initially, the Boston Harbor disposals took place during a 3-hour window at high tide. This timeframe allowed for maximum volume in the water column and minimal sea current effects.[19] Bottom dumping barges were directed over the CAD cells via GPS where they quickly released the contaminated sediments. Quick release of the material significantly reduces the effect of spreading contaminants as the force of the falling sediment pulls in the surrounding water rather than allowing contaminants to dissolve outward beyond the water column. Column tests were performed following each disposal in accordance with the WQC. As the Boston Harbor project continued, disposal was moved to low tide in order to avoid high traffic harbor activities that are usually associated with high tide. Water monitoring tests that followed showed similar results to those at high tide.[20]

A total of 18 monitoring events following disposal were performed during Phase 2 of the BHNIP. Turbidity measurements were taken directly over the CAD cell to assess plume potential and verify direction of current. Values greater than 1000 NTU were detected below the rim of the cell, with readings of 100 to 200 NTU in the water column above the cell. At the 300 ft. point down current from the cell, turbidity readings above 100 NTU were detected in only a limited number of events for durations of only several minutes. Readings never exceeded the criteria set in the WQC and returned to levels close to background readings within 4 – 6 hours of the disposal event. Background concentrations for total suspended solids ranged from 5 to 15 mg per liter. Concentrations at the 300-ft. down current location were generally 2 to 4 times higher than background readings but also returned to acceptable levels by the 4-6 hour sampling time.

Testing for heavy metals revealed no significant accumulations above background or down current levels for Arsenic, Cadmium, Chromium, Copper, Lead, and Zinc. Total Mercury was detected in most samples at levels less than 0.02 µg per liter. On four occasions, concentrations were above the chronic water quality of 0.025 µg per liter. These concentrations of 0.030-0.036 µg per liter all occurred at the 300-ft. down current location immediately after disposal. In these cases, levels dropped below the chronic criterion in the 4-6 hour samples.

Plume tracking following Boston Harbor disposal events showed results similar to those found during excavation. Elevations of turbidity generally remained within the boundaries of the cell itself, with limited down current transport. Only two monitoring events detected concentrations of PCBs, with the highest concentration of 0.19 µg per liter occurring at a background station. Dissolved oxygen concentrations were very similar to background and to down current concentrations which ranged from 4-11 mg per liter as the monitoring was performed throughout the year.

Providence Harbor

Similar monitoring events took place on the Providence Harbor project. The WQC specified additional sampling of silver and copper if the disposal plume was identified at > 10 NTU above background at the 1,500 ft. down current compliance location.

Turbidity was elevated only in the lower water column when measured immediately over the cell, with a maximum value of 50 NTU. Sampling performed across the channel and along the axis of the plume revealed only slight elevations of turbidity in the lower half of the water column, up to 12 NTU compared to ambient values of 3-5 NTU. This elevation was considered more likely related to the ongoing dredging rather than the disposal activities due to the position of the dredge in relation to the monitoring point. Monitoring at 90 minutes confirmed uniform turbidity of 3-4 NTU across the entire channel.[21]

Monitoring for PRHMDP required **TSS** readings at background locations prior to disposal events and at 1,500 ft. down current of the CAD cell in which disposal occurred. Dredging occurred at the same time as disposal on all but two of the monitoring events so elevated **TSS** readings can not be easily correlated to disposal alone. Background concentrations ranged from 4 to 35 mg per liter for high/ebb tide and 7 to 55 mg per liter at low/early flood tide. **TSS** concentrations at the 1,500 ft. station ranged from 9 to 75 mg per liter at high/ebb tide and from 10 to 69 mg per liter for low/early flood tide with highest concentrations occurring in the middle to lower portion of the water column.[22]

Dissolved silver concentrations at PRHMDP were less than the reporting limit of 0.5 µg per liter for all samples. Dissolved copper was detected in most samples, with concentrations ranging from less than 1 µg per liter to a maximum of 8.2 µg per liter. Concentrations were generally higher at depth with only one sample, which was taken prior to disposal at the up current background station, above the chronic/acute water quality criterion for copper.[23]

No apparent trends in dissolved oxygen were noted at the PRHMDP during disposal events and readings were relatively consistent before and after disposal events, as well as, both up current and down current of the disposal location.

Toxicity Testing

A limited amount of biological testing was required to further investigate water quality impacts associated with CAD cells. Toxicity testing was used on shrimp (*Mysidopsis bahia)* and mussels (*Mytilus edulis*) to determine if concentrations noted above produced an adverse effect on marine organisms after prolonged exposure. Mortality, number of young per female and growth are generally used as measures of chronic toxicity.

Test results for BHNIP revealed at or near 100% survival rates for all samples and no differences in growth between the reference site and down current of the disposal cells for the two sets of tests performed. Fertilization tests using sea urchins (*Arabacia punctulata*) showed low fertilization (<33%) for the August 1998 test which was attributed to an impact unrelated to the project. When the test was done again in 1999, results showed approximately 90% fertilization for all samples.

Testing for bioaccumulation of organics in Boston Harbor showed a consistent pattern of highest concentrations upstream decreasing to lowest concentrations further out of the harbor for both PCBs and PAHs (polycyclic aromatic hydrocarbons). This pattern was consistent with a known source upriver and deemed unrelated to CAD cell activities.

Sea Urchin toxicity testing for PRHMDP showed 98-100% fertilization, 86-100% embryo survival, and 88-98% embryo development.

Capping

The most significant concern for the capping of CAD cells is the potential resuspension of contaminants into the water column. Because dredged material is very soft, fine-grained sediment, it is subject to shear failure under the weight of the initial layers of capping material, resulting in contaminated sediments being pushed sideways and upwards out of the CAD cell.[24] Shear failure can be significantly reduced by careful consideration of the material properties of both the dredged sediment and the cap, consolidation time before capping, and the method of placing the cap. Further consideration should be given to techniques for monitoring the thickness and coverage of the cap, and its long-term performance when used in shipping channels.[25]

The water quality certificate for BHNIP required that the 9 CAD cells be capped with a three-foot layer of clean sand. The first three cells, capped in November, 1998 by a hopper dredge under its own propulsion, had consolidation times between 30 and 52 days. Post-cap monitoring revealed variations in the thickness of the sand caps, mixing between the sand cap material and maintenance material, and significant volumes of maintenance material over the sand caps. Additionally, the original cap thickness in excess of 4 ft. had sunk to 3 ft. lower than before capping. These results prompted an amendment to the WQC to allow longer consolidation times prior to capping (60-120 days) and to require minimal maneuvering of the hopper dredge over the CAD cell during cap placement.

The second capping operation included cells that were filled over extended periods of time (221 and 158-day periods) and allowed to consolidate for 155 and 152-day periods. The larger cell had periods of both consolidation and distribution of sediment over its large surface area. Cap monitoring showed a distinct sand cap over most of the surface area of both cells. The elevation of the top of the cell also increased with placement of the capping sand. Monitoring also revealed areas, called *diapers*, where silty material appeared at the surface of the CAD cell and sand appeared at depth. The Corps surmised that the diapers were caused by "localized instabilities where fluidized silty material within the cell was driven upward through the cap as pressure within the cell increased with the loading of the sand cap on top."[26]

Capping of the final two cells, cell M8 and cell M19, was monitored in detail as part of the EPA's National Risk Management Research Laboratory's study of contaminants released into surrounding water column before, during, and after capping. Cell M8 was filled over a 146-day period and allowed to consolidate for 130 days before being capped, and Cell M19 was filled over an 80-day period and allowed to consolidate for 232 days before being capped.

The cells were capped by pushing the partially opened hopper dredge over the CAD cell with a tugboat and placing a smaller layer, called *lifts,* of sand over most of the two cells followed by successive layers to increase the cap thickness. This approach was significantly different from the more conventional cap placement methods such as releasing material from a fully opened hopper, slow release by partially opening hopper doors during placement, and spreading by placement through a hopper drag arm. Concentrations of PCBs measured during capping ranged from below detection to .084µg per liter.[27] The highest reading was measured during the first lift and was the only PCB detection that exceeded the BHNIP water quality criterion of .03µg per liter. Total suspended solids and contaminant concentrations dissipated rapidly after all capping events. The study found that resuspension of contaminants was significantly reduced using a series of lifts when adding the CAD cell cap. Once the initial layer of capping material was in place, subsequent lifts could be placed more rapidly with less concern for resuspension.[28]

Post-Cap Monitoring

A detailed evaluation of the Boston Harbor CAD cells, sponsored by the DAMOS Program, was conducted one year after the capping of the final two cells. The survey indicated that each CAD cell maintained the vertical stratification of dredged material and overlying cap material. Bathymetric data showed that consolidation of capped dredged material was following the natural topographical contours of the sea floor.[29] Cell surfaces had also recolonized with benthic characteristics similar to reference areas in the Boston Harbor. Monitoring of the Cell M19 showed healthy populations of finfish, crabs, and lobsters, as well as the presence of lobster fishing gear. This was viewed as a good indication that the CAD cell area had become a relatively productive area of the seafloor.[30]

Fisheries Protection

Boston Harbor

Areas of Boston Harbor that were scheduled for dredging and disposal cells included habitat for key fishery species such as winter flounder, rainbow smelt, blueback herring, and alewife. The WQC specified protective measures that included specialized techniques and the restriction of any blasting in the areas with anadromous fish from between 15 February and 15 June. A observer from the MA Division of Marine Fisheries and a fish-detecting sonar system were required for all blasting events to ensure schools of fish were not present at the time of blasting. Additionally, certain CAD cell construction, disposal, and blasting events required a fish startle system in addition to the fishery observer and sonar system. The deterrent system was used only when large numbers of fish were encountered. As the water temperatures warmed in the spring, more individual fish were detected but the schools of fish known to be moving up through the harbor were not observed in the immediate vicinity of the dredging or disposal areas.[31]

Providence Harbor

Dredging windows, which restricted activities to specified times of the year, were employed as a means to minimize impact to fish populations and habitat associated with the PRHRMD project. Of greatest concern were impacts to winter flounder (*Pseudopleuronectes americanus*), particularly from sediment disposition sensitive life stages of eggs and larvae. A field study was performed during the 2003-2004 dredging window which compared actual eggs and larvae counted next to the dredge site against those counted in a background location. While significantly more sediment was deposited adjacent to the dredge, no significant difference was found between the two sites in the number of live eggs and larvae.[32]

Conclusion

CAD cells have been the chosen technique for navigation dredging and sediment remediation projects in several harbors around the world: Hong Kong, China; Rotterdam, Netherlands; and several ports in the United States, including Los Angeles, Puget Sound, and the St. Louis River. Monitoring has shown that impacts can be minimized near the event sites and are short in duration.[33] Reduced surface area for contaminant release and less potential for human contact are documented advantages to CAD cell remediation because contaminants are confined within the smaller footprint of the cell.[34] When compared to upland disposal or no-action alternatives, CAD cells have been shown to reduce overall risk to environmental and human health.

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